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TILLAGE EFFECTS ON SEVERAL SOIL PHYSICAL PROPERTIES AND CROP YIELD IN A MALAYSIAN PADDY FIELD

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ABSTRACT: *Tillage operations are carried out to control weeds, incorporate soil amendments, and to establish conditions favorable for plant root development. Studies showing the degree to which various soil properties are altered due to tillage and the subsequent effect on crop yield are scarce. This study was undertaken to evaluate the changes of several soil properties (bulk density, cone index, plasticity index, aggregate uniformity coefficient, organic matter content and pH) resulting from tillage treatments, consisting of factorial combinations of forward speeds achieved with four tractor transmission gear ratios (Gear 1 High, Gear 2 Low, Gear 3 Low and Gear 4 Low) and three rotary tilling speeds (140rpm, 175rpm and 200rpm). The effect of the alteration in these soil properties due to tillage on the potential yield of rice was also investigated. The tillage implements included an 80"-rotavator which is commonly used for the first rotavation and a 110"-rotavator which is used for both the second and third rotavations in Malaysian paddy fields. Generally, a decrease in the soil properties was observed following tillage, which demonstrates the temporal variability of the soil properties due to tillage treatment effects. Accordingly, there were variations in mean yields among the tillage treatments. Regression analysis showed that 96% of the rice yields variation could be explained linearly by all the soil properties considered in the study. Results indicate that properties of the top soil can be used to establish mathematical relationships for predicting the potential yield of rice in paddy fields. The soil-yield relationships obtained could be employed in quantitative productivity classification of rice lands.*

1.0 INTRODUCTION

Agricultural production systems may adversely affect on soil physical and chemical properties resulting in a decline in crop productivity. Soil physical properties are altered every time a tillage implement is used (Emmond, 1971; Wells and Treesuwan, 1978; Bolton *et al.*, 1981; Hallmark and Barber, 1981; Colvin *et al.*, 1984; Ahmed and Haffar, 1993), but field data to show the degree to which these properties are altered following tillage are rare. Past experimental results reported to have shown that measured soil physical and chemical properties can help in field management zones for maximizing benefits from fertilizer application (Roy *et al.*, 2002; Eltaib *et al.*, 2002), and can give possible benefits of site-specific soil and vegetation management or precision agriculture (Ryu *et al.*, 2002; Gang *et al*, 2002). The deep tillage has been reported by many researchers to have beneficial effect on crop production by improving soil physical and chemical properties. However, Maurya (1993) recommends the combination of shallow and no-tillage in a yearly cultivation and occasional deep soil tillage as the most appropriate practice for irrigated soils in semi-arid tropics. In rice fields, the smaller soil clod sizes are important in obtaining high yields. However, very small soil clods resist root growth, which may have great influence on crop yield (Neill, 1979; Yamada *et al.*, 2002). In rotary tillage operations, the condition of the tilled soil are controllable by changing tractor's running velocity and rotary speed of the tiller blades (Yamada *et al.*, 2002).

Suhaimi *et al.* (1986) pointed out that, an increase in rice productivity in Malaysia has been achieved through the introduction of high yielding varieties and improved crop management practices, but wide differences are still remaining in yield among the major rice growing areas, that is the granary areas, of up to about 50%, and to some extent between seasons (about 10%). Ismail *et al.*(1991) stated that the characteristics that differentiate rice productivity in these granary areas are expected to be due to climate, soil, and crop management. For proper decision-making on the best use of the soils of these granary areas, determining the physico-mechanical and chemical properties of the soils is essential. Large-scale farming will require the use of heavy farm machinery. For planning purposes, a complete database on the behavior of lowland soils in Malaysia and their relative productivity is necessary. Field data showing the degree to which various soil properties are altered by and following tillage and the subsequent effect on rice yields are scarce. The main aim of this study was therefore to quantitatively evaluate the effects of within-field variability of soil properties on crop yield under irrigated farming conditions. The specific objectives were:

1. To investigate the differential effects of rotary tillage on the physico-chemical properties of the soil and rice yield in a Malaysian paddy field.
2. To identify soil physical properties of the paddy field that have significant influence on the rice yield.

2.0 MATERIALS AND METHOD

2.1 Experimental design

A two-factor experiment arranged in a completely randomized design was conducted on rice seed multiplication plots at the Sungai Burong Compartment of the Tajong Karang Rice Irrigation Scheme in the Northwest Selangor Integrated Agricultural Development Project. The project area is located on Latitude $3^0$35"N and Longitude $101^0$05"E in the Kuala Selangor and Sabak Bernam Districts, Malaysia. Two experimental factors and their levels were: transmission gear ratio – Gear 1 High (G1), Gear 2 Low (G2), Gear 3 Low (G3), and Gear 4 Low (G4), and rotor speed – 140 rpm (R1), 175 rpm (R2), and 200 rpm (R3). The treatments were a combination of these factors in a factorial manner as follows: G1R1, G1R2, G1R3, G2R1, G2R2, G2R3, G3R1, G3R2, G3R3, G4R1, G4R2, G4R3.

2.2 Data collection procedure

Prior to tillage operations, undisturbed core soil samples were taken at three different locations within each experimental plot using 70 mm x 40 mm brass ring core samplers at two depths (0-100 mm and 100-200 mm). Soil samples were used in the determination of soil moisture content and bulk density using the technique described by Brady and Weil (1999). Bulk soil samples were also collected for the purpose of characterizing the soil in the study area. Before harvest, three measurements from each of bulk density, aggregate uniformity coefficient, organic matter, soil pH, and plasticity index from the 0-100 mm and 100-200 mm depths were again made in crop rows, in each plot. Samples for aggregate uniformity coefficient, organic matter, soil pH, and plasticity index were mixed and one representative sample for each tillage treatment was analyzed. A Standard ASAE cone penetrometer, having a cone base diameter of 4 mm and a tip angle of 60°, was used to measure soil penetrometer resistance at 9 locations in each plot at 25.40 mm (1 inch) increments to a depth of 152.40 mm (6 inches). Values of the cone index were then computed following ASAE standard procedure and guidelines. Organic matter content of each soil sample was assessed using the method of Walkley and Black (1934). Particle-size distribution was performed using the Pipette method (Day, 1965). Gravimetric water content of the soil under field conditions was determined by drying it in an oven at $105^{0}C$ for 24 hours.

2.3 Data analysis

Correlation analysis was carried out on the data set to test the significant relationship between the soil properties and rice yield. A correlation matrix among each of the soil properties and yield was produced to identify properties that are autocorrelated starting with all the soil properties and then only properties identified through stepwise regression analysis to significantly affect the rice yield, linear multivariate models of the following form were fitted:

$$Yield = B_0 + B_1X_1 + B_2X_2 + ... + B_nX_n + e$$

where e is random error; X_1 to X_n, the independent variables (i.e. soil properties) in each data set, and B_0 to B_n , the empirical constants, and analysed to estimate the B's using the step-wise multiple regression technique.

3.0 RESULTS AND DISCUSSION

3.1 Soil analysis

The mean values of the soil properties determined in the study are presented in Table 1 for soil sampling before tillage operations (BT) and before harvesting (BH).

In general, it is difficult to quantify soil property changes imposed by tillage. However, it can be observed from Tables 1 and 2 that there was an overall decrease in most of the soil properties investigated, possibly as a result of the tillage treatments applied to the experimental plots. The few exceptional cases of increased values may have stem from other practices such as irrigation and fertilization, or conditions induced by natural processes such as rainfall or dessication during the growing period. A paired t-test showed that there was a significant decrease in bulk density, pH (H_2O) and pH (KCl) among soil sampling before tillage and before harvesting (Table 2). Organic matter was barely not significant at the 5% level.

3.2 Yield analysis

The average rice yield harvested was about 6.65 Mg/ha. There were some differences in the mean yields, that variations in the mean yields were all attributed to the treatment effect (tillage practices). An analysis of variance was performed to determine if there was any significant difference among the yield means. The p-value was 0.0020 while the coefficient of variation was 24.6%. Duncan's multiple range test for differences (α = 0.05) showed that treatment G4R2 had the highest mean yield which was significantly different from G1R1, G1R2, G2R1, G2R3, G3R3 and G4R1, but not from G1R3, G2R2, G3R1, G3R2 and G4R3. Analysis of variance also showed that there was no individual significant effect of gear ratio G ($F = 1.87$, $p = 0.1405$) and rotor sped R ($F = 2.10$, $p = 0.1283$) on yield, but there was highly significant interaction effect ($F = 5.19$, $p = 0.0001$) of the two parameters on yield.

3.3 Correlation analysis

Correlation analysis carried out for the soil parameters collected after tillage treatments (i.e. before harvesting) showed that some of the variables were intercorrelated, and only a few were significantly correlated with rice yield (Table 3). For this reason, some of the variables were eliminated through stepwise regression backward elimination analysis in order to identify and establish a relationship between the rice yield and soil properties that significantly affected the yield.

When all the soil parameters were considered in the analysis, a highly significant relationship with high coefficient of determination ($r^2 = 0.96$) was obtained. The prediction equation relating the yield and all the soil parameters was:

Yield (7) = -33.15 + 18.54BD – 5.46CI + 0.13PI + 0.98AUC + 1.12OM + 1.34pH_2O + 1.06pHKCL

Yield (7) = 0.76BD – 0.17CI + 0.51PI + 0.49AUC + 0.74OM + 0.42pH_2O + 0.23pHKCL

(With Standardized Coefficients)

$$(\text{with } r^2 = 0.96 \text{ ; } F_{7,4} = 12.709^* \text{ ; } p = 0.014)$$

When some of the parameters were eliminated through stepwise regression analysis, an adequacy of $r^2 = 0.93$ was attained in the yield prediction model with all the variables significantly ($F_{5,6}$ = 16.70**) contributing to the model. The resultant equation was:

Yield (5) = -30.48 + 17.81BD + 0.15PI + 1.18AUC + 0.88OM + 1.35pHH_2O

Yield (5) = 0.73BD + 0.60PI + 0.59AUC + 0.58OM + 0.42pHH_2O (With Standardized Coefficients)

$$(\text{with } r^2 = 0.93 \text{ ; } F_{5,6} = 16.70^{**} \text{; } p = 0.002)$$

The standardized coefficients indicate the relative contribution of each of the soil parameter to the model with respect to each other; the higher the value, the more its contribution to the model. The linear relationship between the actual yield and predicted yield (Y_7) is illustrated in Figure 1.

Statistical analysis indicates that 93% of the rice yield variation can be explained by the five soil parameters that are observed to be significantly affect on the yield in this present study. The remaining 7% is expected to be due to influences by other factors, such as other soil parameters, weather, pests and diseases, crop management practices and random error.

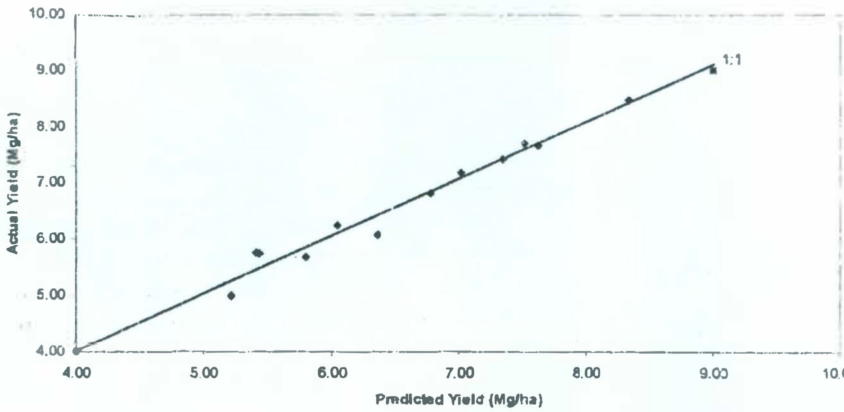

Figure 1. Relationship between Actual Yield and Predicted Yield (Y_7)

4.0 CONCLUSIONS AND RECOMMENDATIONS

1. As can be observed from Tables 1 and 2, there was temporal variability of the soil properties over the rice growing period, which may be attributed to tillage effect, irrigation, fertilization, etc.
2. Stepwise regression backward elimination analysis showed that only five of the soil parameters considered in the present study had significant effect on the rice yields, but this had minimum effect on the adequacy of the model. This implies that yield can be predicted by

using only these minimum number of soil parameters, even though the model is less accurate ($r^2 = 0.93$) compared to considering all seven soil parameters with higher accuracy ($r^2 = 0.96$).

3. Results indicate that properties of the top soil can be used to establish mathematical relationships for predicting potential yields of rice in paddy fields.
4. The soil-yield relationships established in such a study could be employed in quantitative productivity classification of rice lands.
5. As soil analysis is time-consuming, expensive and requires good laboratory facilities, it is necessary to include in yield prediction studies only soil properties that are believed to have great influence on yield. Soil parameters that have very little or no significant effect on rice yields could be ignored.
6. There is need to carry out further verification of the established relationship between soil properties and rice yields in other geographical locations with different rice varieties, soil types, climatic conditions and management practices.

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Table 1. Mean values of soil properties in experimental plots before tillage (BT) and before harvesting (BH)

Tillage Treatment	Bulk Density ($Mg\ m^{-3}$)		Cone Index (MPa)		Plasticity Index (%)		Aggregate Uniformity Coefficient (%)		Organic Matter (%)		pH (H_2O)		pH (KCl)	
	BT	BH	BT	BH	BT	BH	BT	BH	BT	BH	BT	BH	BT	BH
G1R1	0.87	0.83	0.25	0.18	6.98	3.27	9.75	9.05	4.90	4.85	4.74	4.89	5.15	3.30
G1R2	0.86	0.75	0.14	0.18	8.32	5.78	9.48	9.73	6.25	4.56	5.06	4.65	4.70	3.67
G1R3	0.84	0.80	0.28	0.19	11.16	2.10	9.17	9.68	5.65	6.08	4.84	4.69	4.49	3.65
G2R1	0.84	0.75	0.16	0.18	7.02	6.27	9.45	9.50	5.72	5.41	5.17	4.16	4.73	3.67
G2R2	0.85	0.83	0.14	0.19	6.29	4.84	8.13	11.15	4.77	4.27	4.70	3.95	4.89	4.04
G2R3	0.85	0.79	0.24	0.22	8.06	4.05	10.61	9.20	5.63	6.00	5.09	4.59	4.78	3.54
G3R1	0.86	0.89	0.11	0.15	3.32	7.14	9.44	9.90	4.48	4.29	5.05	4.21	4.92	3.89
G3R2	0.82	0.86	0.24	0.23	10.85	5.81	9.88	9.53	5.36	5.29	5.14	4.49	5.01	3.78
G3R3	0.91	0.76	0.14	0.17	9.98	1.87	9.13	9.61	5.35	4.60	5.04	4.95	4.69	3.77
G4R1	0.87	0.80	0.16	0.10	8.40	3.53	9.02	9.81	5.11	4.15	4.34	4.49	4.93	3.68
G4R2	0.90	0.81	0.20	0.19	3.60	15.03	8.96	9.49	4.90	5.04	5.21	4.82	4.95	3.89
G4R3	0.90	0.78	0.15	0.17	7.31	12.93	10.72	9.45	4.55	4.03	5.26	4.95	5.05	4.14

Table 2. Paired t-test comparison of mean soil parameter values before tillage (BT) and before harvesting (BH)

Parameter	Mean	Std Dev	Std Error	T	Prob > |T|
Bulk Density	0.6000	0.0577	0.0167	3.6033	0.0041
Cone Index	0.0050	0.0470	0.0136	0.3685	0.7195
Plasticity Index	1.5558	5.9062	1.7050	0.9125	0.3811
Aggregate Uniformity Coefficient	-0.1967	1.1498	0.3319	-0.5925	0.5655
Organic Matter	0.3417	0.5985	0.1728	1.9774	0.0736
pH (H_2O)	0.4000	0.3733	0.1078	3.7122	0.0034
pH (KCl)	1.1058	0.2751	0.0794	13.9231	0.0001

Table 3. Correlation matrix of soil properties and rice yield after tillage treatment

Variable	BD	CI	PI	AUC	OM	pH (H_2O)	pH (KCl)
BD							
CI	0.06032						
PI	0.05480	0.05990					
AUC	0.21380	-0.14787	0.09273				
OM	-0.11999	0.63658*	-0.26013	-0.40703			
pH (H_2O)	-0.32423	0.03307	0.15999	-0.68484*	0.05637		
pH (KCl)	0.11686	-0.07763	0.58902*	0.56007*	-0.50746	-0.21175	
Yield	0.68606*	0.30289	0.50133	0.16683	0.12126	-0.09385	0.43535

BD = bulk density CI = cone index PI = plasticity index OM = organic matter
AUC =aggregate uniformity coefficient pH(H_2O) = pH in water pH(KCl) = pH in KCl
* significant at $p \leq 0.05$